

either be received by the weaker beacon as unexpected data or will be an unsynchronized response that is unintelligible. Either case can cause problems at the weaker beacon.

Several techniques can be used to mitigate interference between interconnected beacons (*i.e.*, the ETC facility) operating at the same frequency. Examples of methods used by existing DSRC systems include:

1. Very careful control of power levels and antenna directionality to control the transaction zone;
2. FM capture techniques that use received power level to discriminate at the beacons;
3. Time differentiation where adjacent or nearby beacons operate one-at-a-time in an interleaved fashion; and
4. Power level discrimination at the tag combined with interleaved beacons such that the tag only responds to the appropriate beacon.

Power control and antenna directionality (spatial differentiation) are used to some degree by all beacon systems. The other techniques are used to improve isolation between nearby beacons. In an ETC application, all of these techniques should be reasonably effective. An actual comparison of the effectiveness of each of these techniques and combinations of techniques would require detailed simulation or testing. Since each of these techniques are currently fielded and operating, it is safe to assume that these techniques are effective at mitigating interference between adjacent beacons.

Mitigation of interference between beacons at the same frequency is much more difficult if the beacons are not interconnected. As in the example above, a portable reader will not be physically interconnected to a fixed beacon and thus cannot use most of the mitigation techniques listed above for an integrated beacon system. Power control and antenna directionality can be used to some extent, but the location of the portable beacon relative to the fixed beacon is unknown. The portable beacon may actually be in the center of the intended coverage zone for the fixed beacon. Therefore, power control and antenna directionality will not completely mitigate interference.

Assuming the portable and fixed beacon must operate at the same frequency, the first mitigation technique that might be employed is a protocol for time sharing. The fixed beacon protocol may include a "silent" period which allows the portable beacon to operate in the same zone. This method requires the portable beacon to detect the silent period of the fixed beacon and transmit only during this time period. This method is very inefficient for both beacons. The fixed beacon must incorporate a wasted silent period at all times, even though the portable beacon may only occasionally be present. The portable beacon is also restricted to communicating in small time slots greatly reducing its total effective data rate.

Another cooperative protocol, assuming the fixed beacon uses a slotted TDMA multiple access technique, would allow the portable beacon to "capture" a slot or slots in the fixed beacon's protocol. This protocol would be very complicated and require the portable beacon to

communicate with the fixed beacon as if it were a tag, and the fixed beacon may be required to not transmit its own tone during these time slots.

The portable beacon's best technique for successful communication would use proximity (short distance) and power control to over-power the field strength of the fixed beacon in a small area. The portable beacon would successfully communicate with the intended tag, but the responses from this tag would interfere with the operation of the fixed beacon. The tag's responses to the portable beacon would be a strong interference source received also by the fixed beacon. This interference is likely to be short lived, but if the operation of the fixed beacon were time-critical (*i.e.*, collision avoidance) the interference might have disastrous results.

In short, the problem of mitigating interference between non-cooperative interfering beacons operating at the same frequency is very difficult. It may not be feasible to implement a cooperative protocol that allows a portable beacon to operate within the coverage zone of a fixed beacon. Cost and complexity will likely be high. The best solution may be to use separate beacon frequencies. This option is discussed in the next section.

3.2.2 Different Frequency DSRC Interference Mitigation

In this section interference problems associated with nearby beacons operating at different frequencies will be addressed. It is assumed that the frequencies are all within the operating band of the tag and, as stated in the earlier assumptions, the tag uses a passive or semi-passive technology that reflects all signals within its operating band. In the previous section it was shown that cooperative or integrated DSRC systems can operate at the same frequency with good interference rejection. In this section, it is assumed that the beacons are from separate, non-cooperative DSRC systems intended to communicate with the same tags.

As in the last section, the example to be studied will be a portable beacon operating within the coverage zone of a fixed beacon. The difference this time is that the portable beacon will operate at a different specific frequency within the band of the tag. Again the portable reader will use power control and proximity to transmit a signal to the intended tag which is much stronger than that received from the fixed beacon. The simple AM detection of the tag will therefore only detect the portable beacon's signal and the tag will respond to the portable beacon.

The response of the tag read by the portable beacon will also be received at the fixed beacon. However, the fixed beacon will have filtering that only allows the reception of signals centered at the frequency it is transmitting (probably a superheterodyne receiver). Therefore, the strong signals emanating from the portable reader and reflected by the tag will be filtered out at the fixed beacon's receiver.

The use of different frequencies for two beacons operating in the same area, and the use of power and proximity control does not completely eliminate the interference problem. Since it is assumed that the tag uses a passive or semi-passive reflecting technology, the tag will incidentally reflect *all* in-band signals that it receives. Therefore, the tag responding to a portable beacon will

also reflect and modulate whatever signal power is received from the fixed beacon as well. When this tag is responding to the portable reader, the coverage zone of the fixed beacon is reduced due to the interference reflected by the tag.

Figure 1 demonstrates graphically the reduced coverage zone of the fixed beacon while the portable beacon is receiving data from the tag. The light gray area is the original coverage zone of the fixed beacon; the dark gray region is the coverage while the portable beacon is receiving data from the tag.

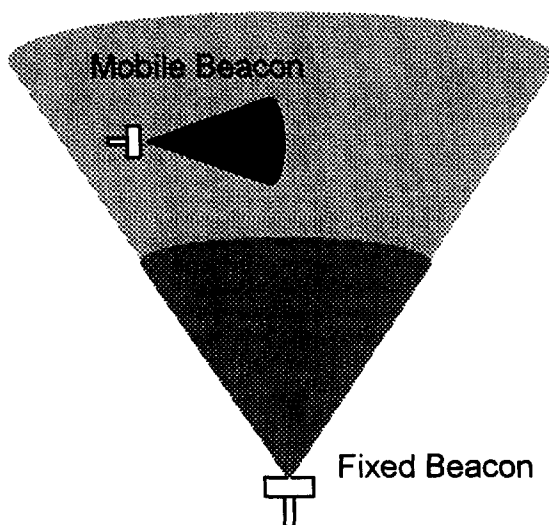


Figure 1. Coverage Zone Reduction Due to Portable Beacon

The reduced coverage range shown in Figure 1 is similar to that for a portable reader operating at the same frequency as the fixed beacon. However, the impact is much less using different frequencies since the fixed beacon will only receive its own signal level reflected incidentally from the tag read by the portable reader and not the elevated signal level from the portable beacon operating on the same channel. Also note that the reduced operating range of the fixed beacon only occurs when the tag is responding (uplinking) to the portable reader. This will likely only occur for a short period of time.

3.3 Installation Groups

Efficient use of applications may be enhanced by implementing some applications with shared equipment installations. This will allow the installation of several applications on the same channel therefore reducing the channel requirement from that required if each application were deployed separately. Applications can be shared by a set of communications equipment if they do not suffer degradation from serial transmission, reception, and processing of the data. Four installation groups are proposed. These groups and the applications they include are as follows:

- In-vehicle signing installation group—In-vehicle signing, railroad crossing warning, traffic network performance monitoring, and traffic network performance feedback;

- CVO installation group— electronic (mainline) clearance, international border clearance, safety inspection, fleet management, and intermodal freight management;
- Intersection installation group—Intersection collision avoidance, emergency vehicle signal preemption, and transit vehicle signal priority; and
- Mobile location interrogation group - off-line verification, ELP, and commercial interrogation.

The remaining DSRC applications have operational characteristics that are not compatible with deployment in a group and can be expected to be deployed independently.

- Transit vehicle data transfer;
- Automated highway system-to-vehicle communications;
- ETC;
- Parking payments;
- Access control; and
- Drive-thru payments.

Channel requirements for all the applications implemented at a group location are included in the description of each group. However, in the next section these channel requirements will be partitioned into assignments for each application.

3.3.1 In-Vehicle Signing Installation Group

The applications in the in-vehicle signing installation group (in-vehicle signing, railroad crossing warning, traffic network performance monitoring, and traffic network performance feedback) are implemented by installing beacons at designated communication locations (see Figure 2). These locations could include places where safety could be increased by monitoring a roadway condition (ice, fog, etc.), where potentially dangerous conditions exist (construction, low visibility, etc.), or where safety could be increased at railroad crossings by warning of tracks being approached or trains about to cross the road (see Figure 3). The locations could also include places where directional information is needed or traffic speed is being tracked with antennas mounted every 1/2 to 1-1/2 miles along selected high-density roadways, at off-ramps, and at access ramps to implement a traffic management function as in the New Jersey Transmit program [6]. The beacon signal pattern must reach each car in each lane of the roadway and can be implemented with several different antenna mounting methods. Some of the methods include the following:

- One or more beacons (antennas) could be mounted over the roadway;
- Several synchronized or multiplexed beacons could be mounted over the roadway with one over each lane;
- For single lane or some double lane roads, the beacons could be mounted on signs or poles along the roadway; and
- For double lane roads, the beacons could be mounted on signs or poles along each side of the roadway.

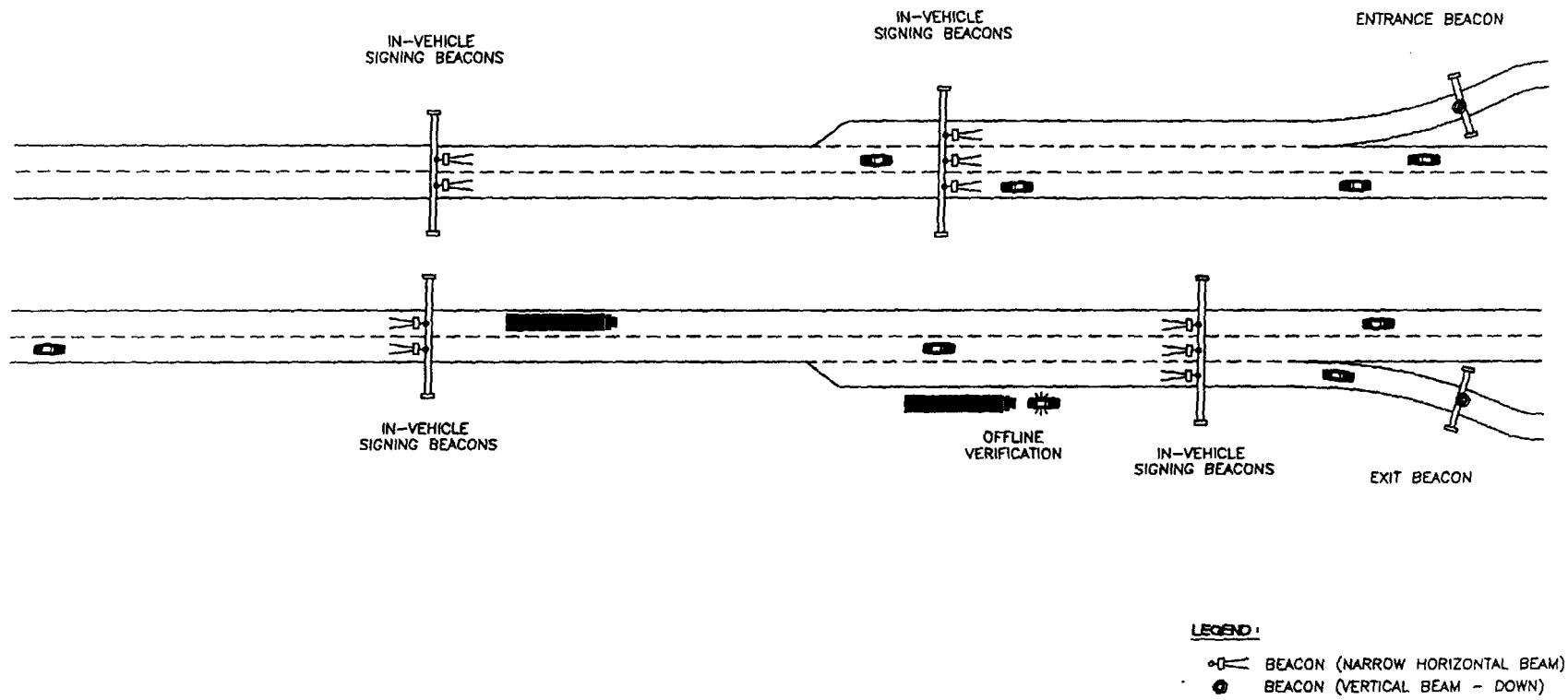


Figure 2. In-Vehicle Signing Installation Group

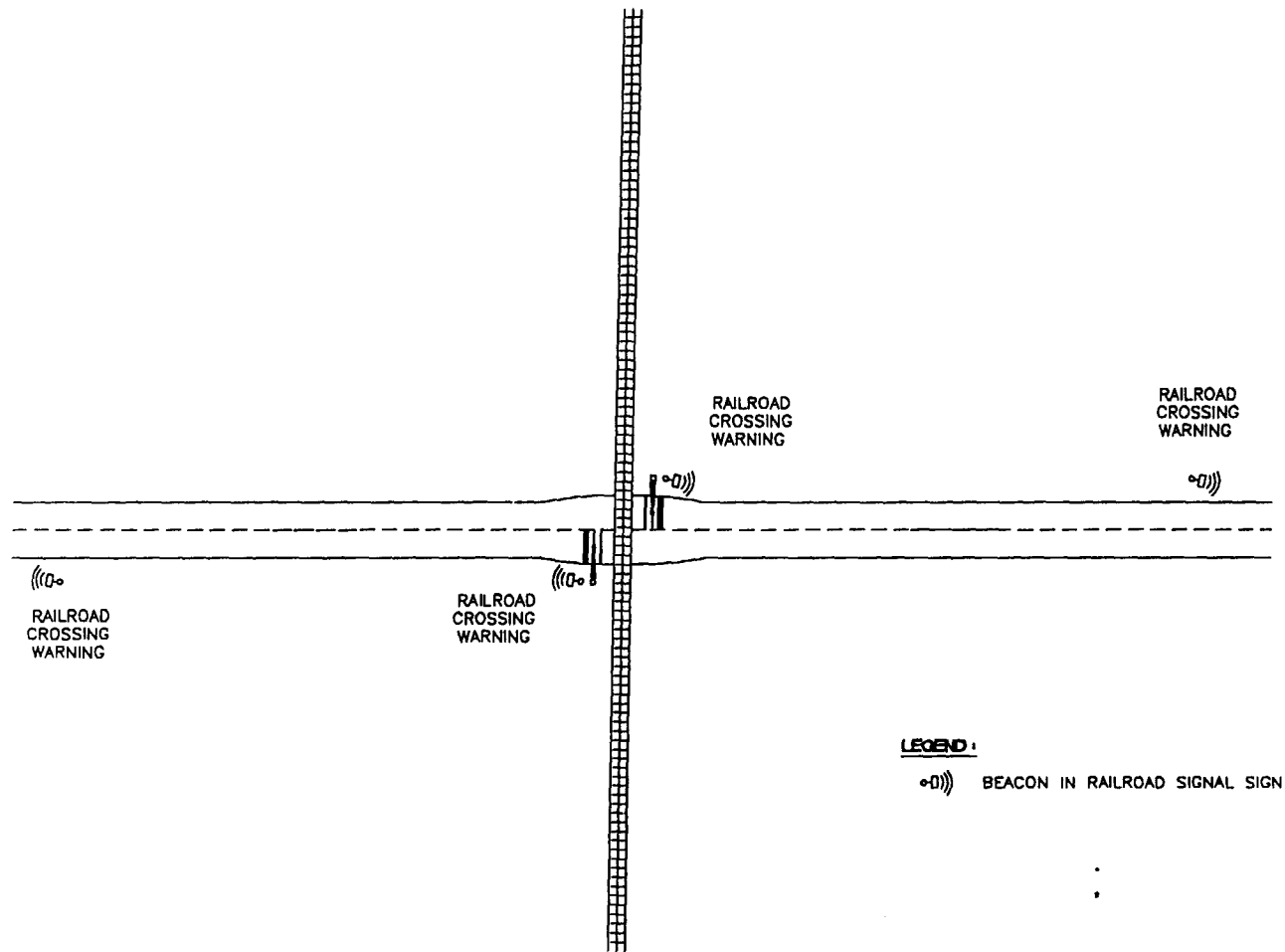


Figure 3. Railroad Crossing Warning

All the implementations except the single lane must use either a broadcast communication protocol to make a one-way transfer of data to the vehicles or a multiple access protocol to transfer data to and from the vehicles, one at a time. Some implementations may even use a broadcast mode in the multiple access protocol. Most systems are currently using a TDMA multiple access protocol with a slotted aloha access scheme. This protocol consists of frames in which there are communications time slots and activation time slots. The activation slots are usually much smaller than the communications time slots and are used by in-vehicle tags to announce their "desire" to communicate with the beacon. A tag randomly chooses an activation slot and quickly announces its identification number to the beacon. The beacon then announces to the tag, using the identification number, when it is permitted to communicate.

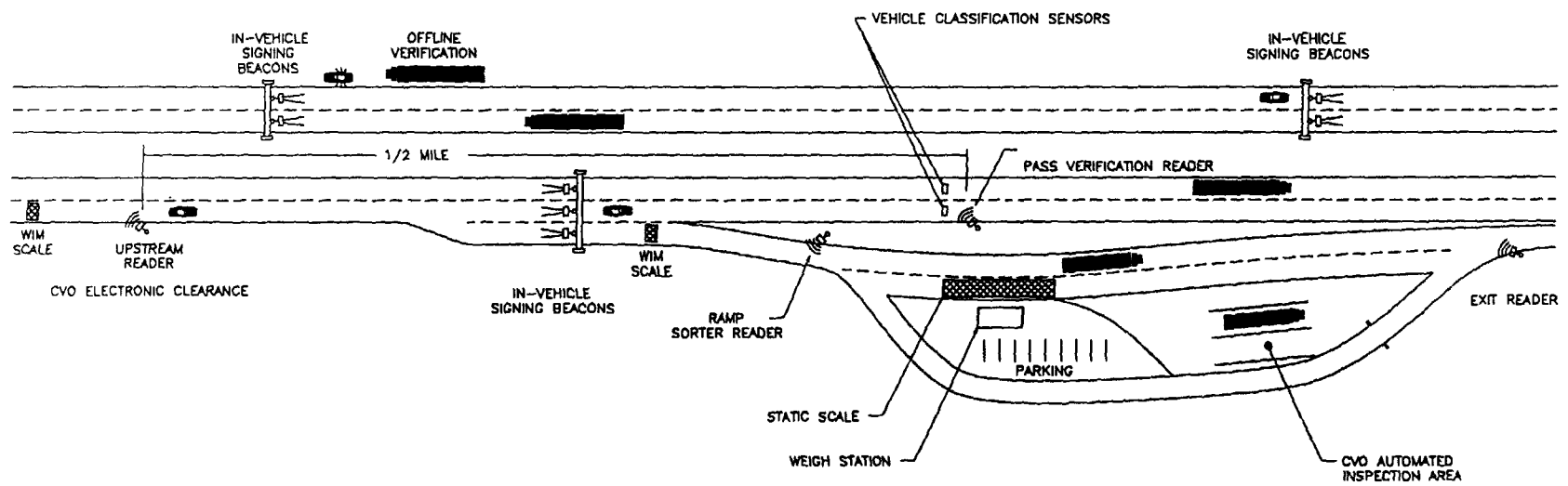
Using this method, the beacons at any particular location can conduct several different information transfers with any particular vehicle to implement a series of desired functions. In a traffic management application, like the Transmit program in New Jersey [6], the system would communicate with a vehicle at a beacon site and compute its travel time (link time) from its previous beacon site communication. However, in future versions, the beacon could next transmit an update of the traffic conditions or other traffic instructions to the tag as feedback from the traffic management center.

In-vehicle signing in many cases could use only one channel and a horizontally directed beacon to transmit and receive at ranges up to about 100 feet (backscatter tags) or 200 feet (active tags) in order to select and communicate with all the vehicles while they are in the communication zone. The range can be extended to between 200 and 300 feet (for both active and backscatter tags) by using a broadcast mode where the beacon transmits and the tag only receives without trying to respond. The communication distance and/or location of the beacon is determined by the amount of information to be acquired, the action the driver has to take and the vehicle speed. In cases where more advanced warning of an approaching hazard is desired, beacons are located ahead of the hazard by an appropriate distance. For instance, in the case of the railroad crossing, beacons would be mounted at the crossing and 300 feet to 1/2 mile in advance of the crossing. Beacons that use more power can be received by tags at distances further than 300 feet, when necessary, but at the cost of increasing the interference-preventing separation distance between beacons. Most beacons can be installed out of interference range at the two-way 100-foot-range power settings, except in some cases of off-ramp or on-ramp installations. In these instances, another channel could be used to prevent interference. The portable in-vehicle-signing beacon implementation would be used for construction, temporary warning or emergency applications. The message of the portable beacon could also be broadcast by nearby fixed in-vehicle-signing beacons where the hazard is in the coverage of the fixed beacon. However, a portable warning sign could be needed downstream of a stationary beacon where it could cause interference by transmitting upstream into a fixed beacon's capture zone. In this case, the portable beacon would need a second channel to prevent interference. Therefore, in-vehicle signing could possibly require two channels for its implementation. However, a mobile location interrogation could also be required at any point along the instrumented roadway, and an additional channel for that application would be needed to prevent interference. The area of the in-vehicle-signing installation would need the allocation of three channels.

3.3.2 CVO Installation Group

The applications in the CVO installation group are electronic clearance (screening), international border clearance, safety inspection, fleet management, and intermodal freight management. Electronic clearance is currently implemented by installing weigh in motion (WIM) scales in the roadway, antennas above the roadway, and tags to the windshield or front of commercial vehicles. Currently, in some applications, a WIM scale and one antenna are installed at the outside lane of the roadway about 1/2 mile before the weigh station to allow time for the vehicle to pull in if necessary (see Figure 4). As a vehicle passes through a capture zone beneath the beacon, the beacon sends signals to and receives signals from the tag to implement the transaction. The second beacon is installed in front of the weigh station. Vehicle classification sensors are used to identify passing trucks that need clearance and this beacon determines if the trucks are authorized to bypass the weigh station. Another WIM scale and third beacon is installed at the entrance of the weigh station to allow the vehicle to have another weight check before it is given the static scale pull-in signal and to update the tag with this information acquired at the weigh station. A fourth beacon is installed at the exit of the weigh station to update the tag with the latest information acquired at the weigh station. Each of these beacons is installed out of the range of the others and all use the same channel. Interference is prevented by careful power level setting and directional orientation of the beacon. The maximum range setting of the beacons used is about 100 to 200 feet.

A safety inspection area is provided for vehicle inspections. These areas are not currently, but could be, instrumented with hand-held readers to allow the downloading of data from the tag and uploading of inspection data to the tag. Vehicle inspection readers may need a separate channel, depending on the separation distance, equipment, and propagation characteristics of the site. In addition, a mobile location interrogation system operating in this area would require an additional channel. The CVO installation would need an allocation of three channels.



LEGEND:

- | BEACON (NARROW HORIZONTAL BEAM)
- || BEACON (HORIZONTAL MULTILANE)
- BEACON (VERTICAL BEAM - DOWN)

Figure 4. CVO Installation Group

International border clearance could be implemented by installing antennas above the roadway, attaching tags to the windshield or front of commercial vehicles and attaching a lock tag to the cargo door of the trailer (See Appendix B). One set of antennas are installed above the roadway about 1/2 mile before the border crossing (see Figure 5). As the front of the vehicle passes through a capture zone beneath the second beacon, the second beacon sends signals to and receives signals from the tag to implement the clearance interrogation. After the vehicle clearance information is transferred and the back of the vehicle has cleared the first beacon. The first beacon interrogates the lock tag on the back of the trailer to determine if the cargo door has been opened since it was inspected. The travel time between the second and third beacon would allow the transaction to be processed and a clearance message prepared for the third beacon. The third lane sorting beacon would be installed at the entrance of the truck inspection area to provide the by-pass or park clearance message to the vehicle. The fourth verification beacon would be installed in the bypass lane of the truck inspection area to determine if passing trucks are authorized to bypass the inspection area.

Hand-held readers would be used in the inspection area on tag equipped vehicles that were instructed to park. This would allow the downloading of data from the tag and uploading of inspection data to the tag. Vehicle inspection readers may need a separate channel, depending on the separation distance, equipment, and propagation characteristics of the site. A sixth beacon would be installed at the exit of the weigh station to update the tag with the latest information acquired at the inspection station. The maximum range setting of the beacons used is about 100 feet.

In addition, a mobile location interrogation system operating in this area would require an additional channel. In-vehicle signing would also require a channel if operated in the area. The CVO international border clearance installation would need an allocation of four channels.

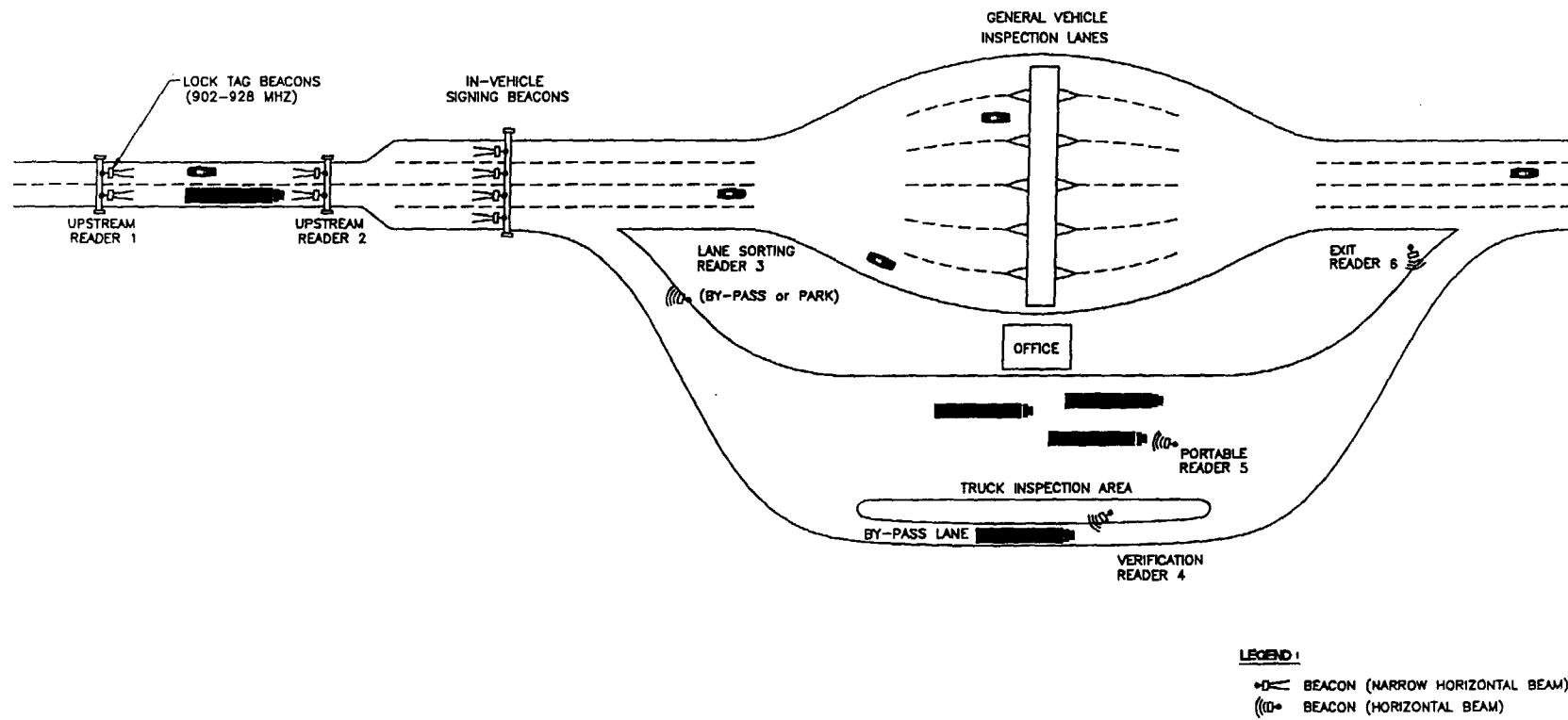


Figure 5. CVO Installation Group – International Border Clearance

3.3.3 Intersection Installation Group

The applications in the intersection installation group (intersection collision avoidance, emergency vehicle signal preemption, and transit vehicle signal priority) are implemented by installing readers at intersections and nominally would use two channels to prevent cross-reads from intersecting lanes (see Figure 6). However, if the beacons are sufficiently separated and an appropriate synchronization scheme is employed one channel could be used. Intersection beacons are expected to use TDMA slotted aloha protocol or similar to communicate with multiple vehicles in the multiple approaching lanes.

The intersection collision avoidance application would, when activated, override all other communication by commanding all tags to listen at the first available frame. The communication would be a one way information flow so the beacon could use its maximum range. The implementation of collision avoidance will also require a series of beacons installed upstream of the intersection. The upstream beacons are needed because for some vehicle speeds the beacon range is not greater than the stopping distance plus the reaction distance of the driver. For example, the stopping distance used in road design for a car at 43.5 miles/hour is 98 feet, and the reaction time of drivers is between 0.2 to over 2 seconds, so at that speed the expected reaction distance is between 12.8 and 127.6 feet, which could make the total distance needed greater than a 200 foot beacon range [7]. A beacon range of from 100 to 200 feet does not allow the intersection beacon enough time to handle faster speeds, slow reaction times, or wet or snow cover conditions. The upstream beacons must be installed to expand the coverage to include more potential collision situations.

The advance notification of an approaching emergency vehicle is also handled by beacons upstream of the traffic flow by 1000 to 3000 feet either as intersection beacons or separate installations. The location of the emergency vehicle and its direction of travel toward the intersection are passed by wireline to the computer controlling the intersection beacons in the figure. The intersection beacons verify the emergency vehicle's arrival and departure to restore normal traffic function. This function could require a separate channel.

Because the transit vehicle data transfer readers are also installed near intersections, a separate channel from the one or two used in the intersection should be used to reduce the possibility of interference. The additional channel is needed because the transit vehicle dedicated short range link may occur for several seconds, may not be synchronized with the intersection equipment, and the intersection readers must communicate on an emergency basis, with no delay or interference, to vehicles in a critical status.

Other applications within the interference zone of the intersection installation group, such as a portable in-vehicle signing application, would need to use another channel. Also, a mobile location interrogation could be required at any point approaching or leaving the intersection and would need an another additional channel to prevent interference. The maximum unrestricted channel allocation for the intersection installation group could be six.

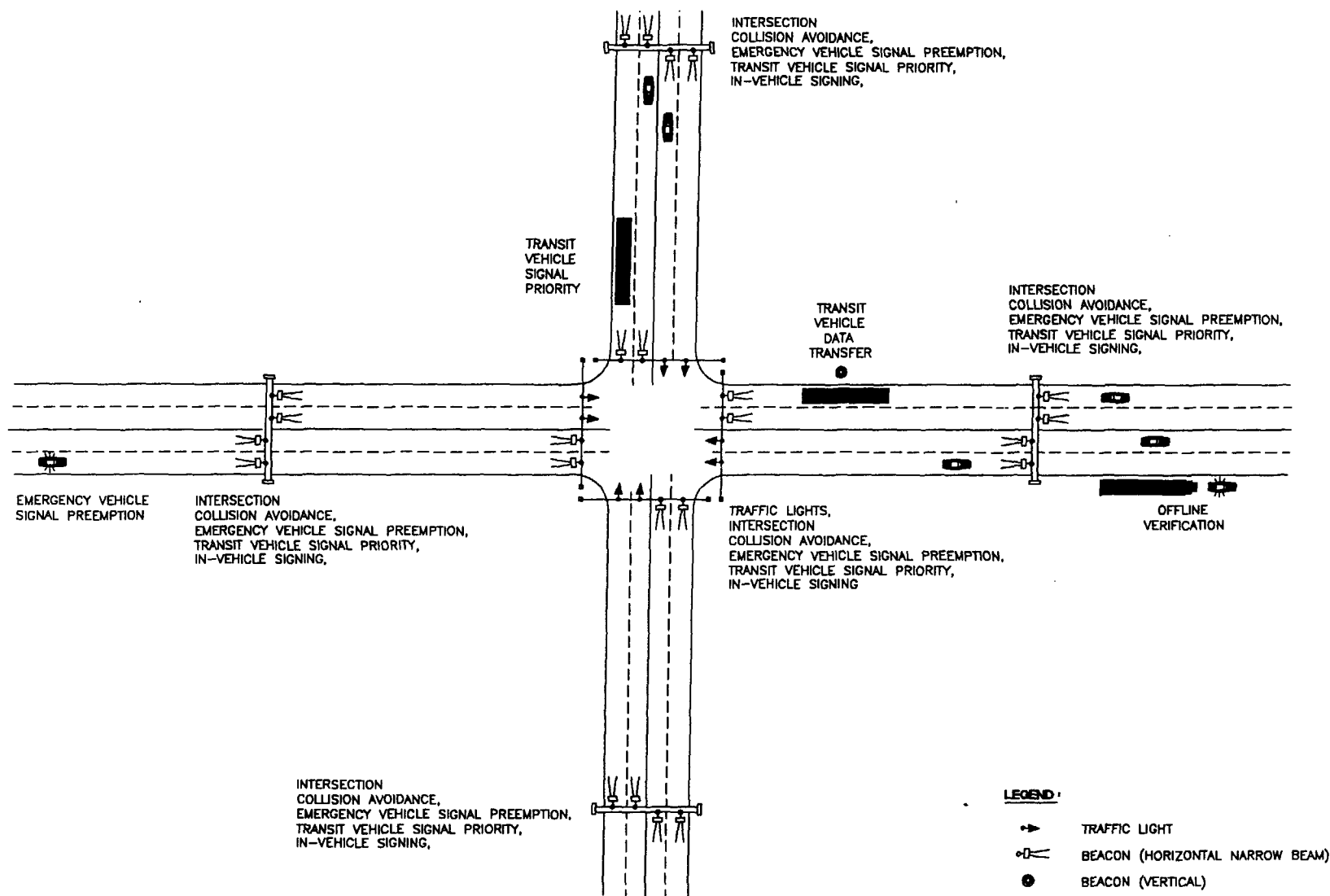


Figure 6. Intersection Installation Group

3.3.4 Mobile Location Interrogation Group

The mobile location interrogation group consists of the off-line verification, ELP and the commercial interrogation applications. The off-line verification applications use hand-held readers to download information from vehicles that are, stopped, disabled, or involved in incidents (see Figure 6). The ELP application uses mobile, stationary, or hand-held readers to download information from vehicles that are in traffic. The commercial interrogation applications use stationary or hand-held readers to download or upload information from vehicles in freight yards and other locations. The off-line verification and commercial applications only require short-range (10 feet), low-power equipment. The ELP application needs the maximum range of about 150 feet to allow an enforcement agent to maintain a safe distance to a subject vehicle. Because these applications may need to be implemented at any location, they must use a separate channel that is not shared by the other applications.

3.3.5 Transit Vehicle Data Transfer

To accomplish transit vehicle data transfer, readers are installed at bus stops, terminals, and other designated areas. The readers pass data to and from the tag on the transit vehicle during stops (see Figure 6). Intersection installation group beacons could be installed at intersections that may be close to bus stops where beacons are installed. However, four characteristics of this installation reduce the possibility of interference. First, the transit vehicle beacon must be operated at low power to prevent interference with the intersection beacons. Second, the location of the beacon within 5 to 10 feet of the transit vehicle tag enables the transit beacon signal to be large, compared to any other source, while using low power settings. Third, the transit vehicle will shield the intersection from a large proportion of the beacon transmission. And, fourth, using a separate channel from the two channels used in the intersection eliminates the remaining interference potential. The additional channel is needed because the transit vehicle dedicated short range link may operate for several seconds, and a preventable accident could occur in that time frame if interference occurs with the collision avoidance beacons.

3.3.6 Automated Highway System-to-Vehicle Communications

Automated highway system-to-vehicle communications transfers data on the operational status and position of the AHS vehicle from the vehicle to the roadside, and transfers AHS operation instructions and AHS roadway status from the roadside to the vehicle (see Figure 7). To accomplish this, reader sets, including antennas, are installed at check-in and check-out points in the transition lanes and, optionally, at design-determined distances along the AHS roadway. AHS should require one channel to perform the required communications. Most of these highways are expected to be located in close proximity and parallel to existing highways with in-vehicle signing or other applications installed. This would create a potential source of interference if AHS did not operate on a separate channel. The maximum range setting of the beacons used is about 20 to 30 feet.

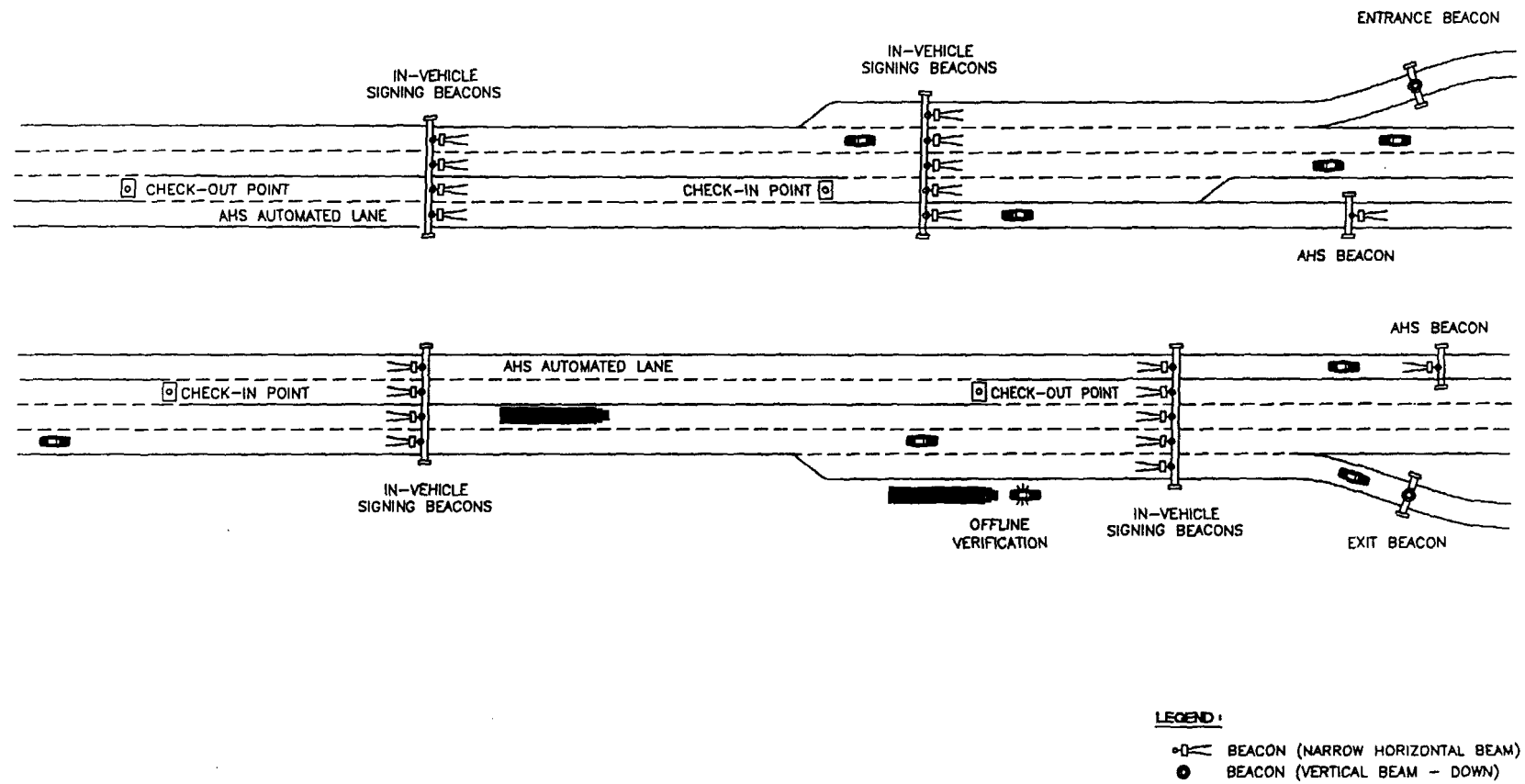


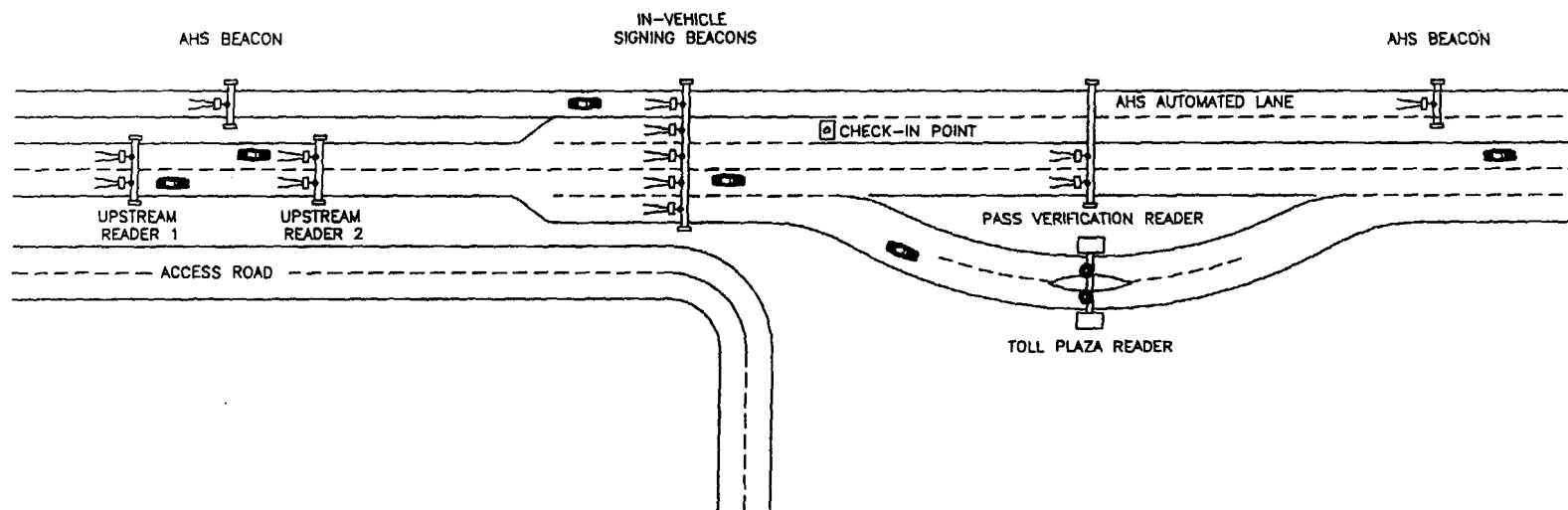
Figure 7. Automated Highway System to Vehicle Communications

3.3.7 Electronic Toll Collection (ETC)

In electronic toll collection, beacons are placed on gantries above toll lanes, and tags are attached to the windshield or license plate of vehicles (see Figure 8). One antenna is typically assigned to each lane. As a vehicle passes through a capture zone beneath the antenna, the antenna sends signals to the tag and receives signals from the tag to implement the toll transaction. To ensure communication with the designated lane and with only one vehicle at a time, beacon synchronization, power control, antenna pattern separation, and antenna multiplexing are used. These interference prevention measures allow one channel to be used for a set of lanes.

Some equipment use a second channel to provide interference-free communications with each set of adjacent lanes, creating a need for two channels. Typically, the original channel is reused if a third set of lanes is instrumented.

In addition, in many toll collection activities, antennas are mounted above the mainline highway, and a pullover toll collection area is provided for non-instrumented vehicles and vehicles whose transactions do not clear. This manual toll collection area is also instrumented with antennas and readers to allow under-funded tags to have additional funds added. This activity could either reuse a channel or require a third channel, depending on the separation distance, equipment, and propagation characteristics of the site. The maximum range setting of the beacons used is about 20 to 30 feet.



LEGEND:

- | BEACON (NARROW HORIZONTAL BEAM)
- BEACON (VERTICAL BEAM - DOWN)

Figure 8. Electronic Toll Collection

3.3.8 Parking Payment / Access Control

The parking payment or access control application is implemented by placing antennas above the lanes entering the parking or restricted area and attaching tags to the windshield or front of vehicles (see Figure 9). One antenna is typically assigned to each lane. As a vehicle passes through a capture zone beneath the antenna, the antenna sends signals to the tag and receives signals from the tag to implement the payment or clearance transaction.

Some equipment use a second channel to provide interference-free communications with each set of adjacent lanes. Therefore, to account for multiple-lane entrance and exit plazas, two channels should be allocated. The maximum range setting of the beacons used is about 20 to 30 feet.

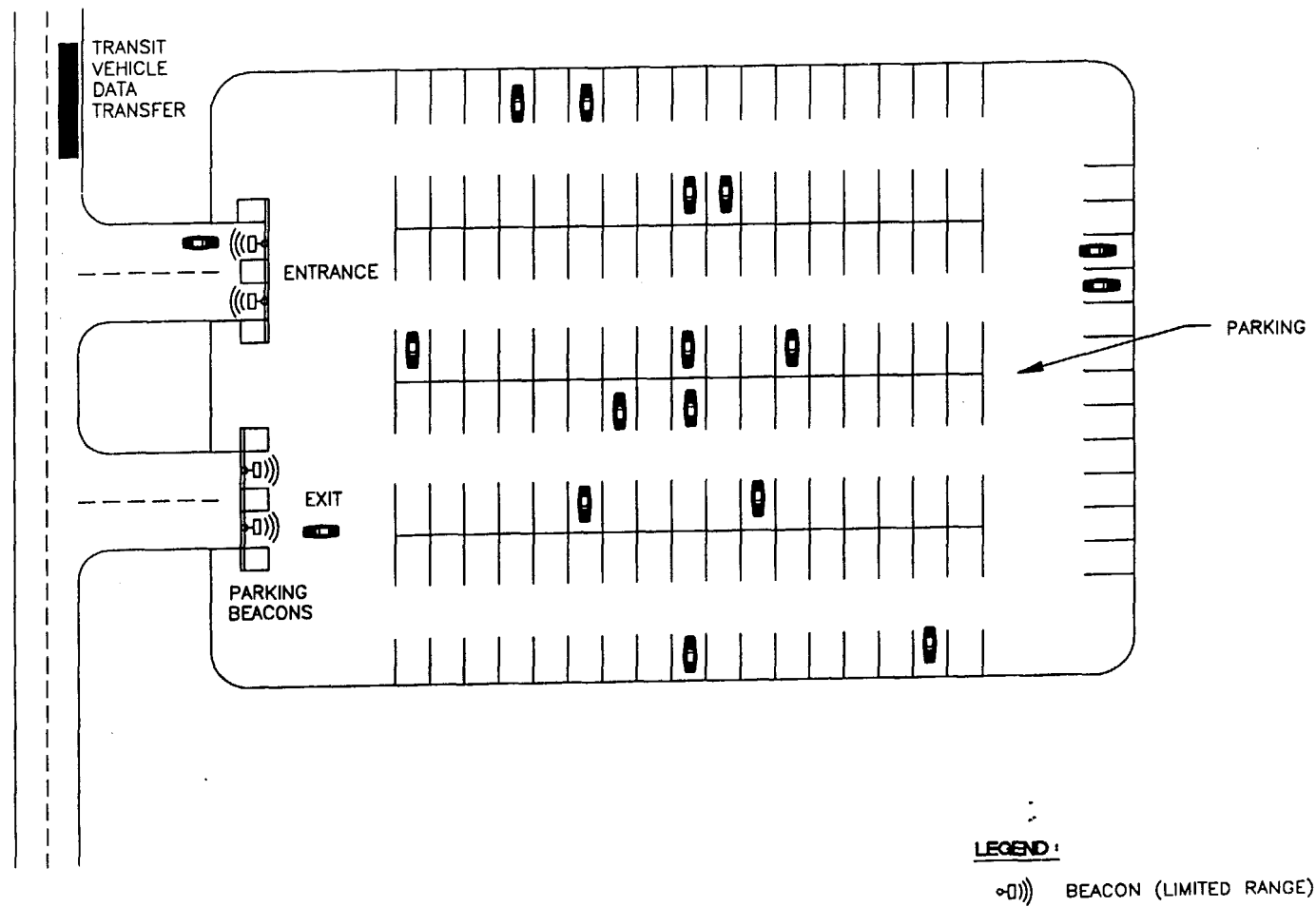


Figure 9. Parking Payment / Access Control Application

3.3.9 Drive-Thru Payments

The drive-thru payment application is implemented by placing an antenna next to the drive-thru lane and attaching tags to the windshield or front of vehicles (see Figure 10). One antenna is typically assigned to each lane. As a vehicle stops in front of the antenna, the antenna sends signals to the tag and receives signals from the tag to implement the payment transaction.

A second channel is needed to provide interference-free communications with each set of adjacent lanes or adjacent business operations. The maximum range setting of the beacons used is about 10 feet.

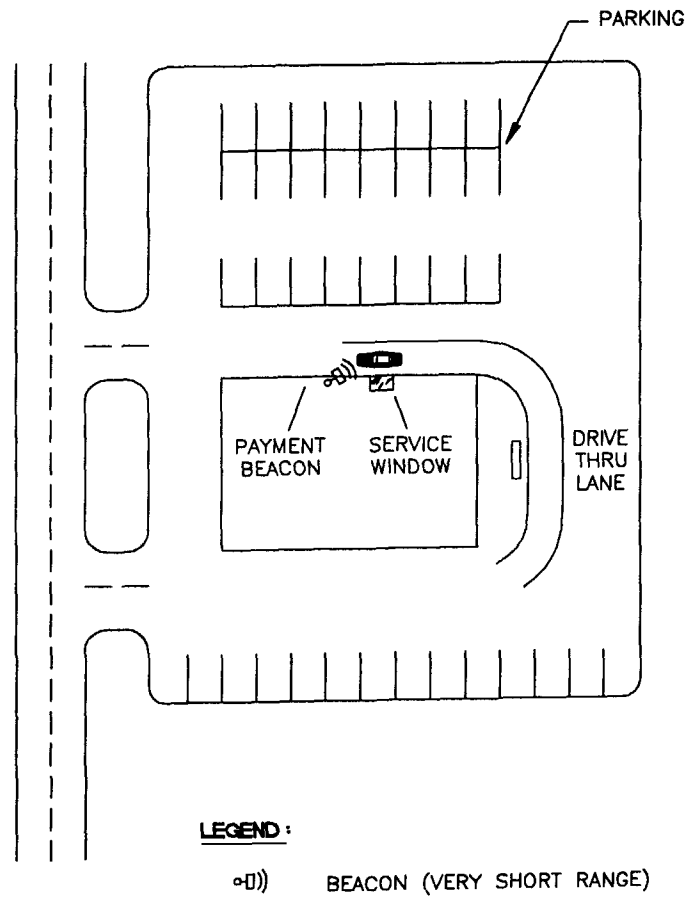


Figure 10. Drive-thru Business

3.4 DSRC Channel Requirements

3.4.1 Individualized Channel Assignment

To begin an analysis of the number of channels required to implement a full DSRC system a reasonable allocation of channels was made based on applications and installation groups. This example of a possible initial assignment of channels is given in Table 1. The channels were assigned in a way that minimizes the occurrence of two or more applications using the same channel in one location. The CVO installation group is almost always located in a different place than an ETC application. The ETC application is usually not located in a place that is near a bus stop. When public parking is located close to one of the other applications the availability of two channels would allow the two most proximate channels to be different.

Table 1. Example Initial Channel Assignment for DSRC Systems

Channel #	Description
1	Fixed In-Vehicle Signing Installation Group
2	In-Vehicle Signing (with a portable beacon)
3 & 4	Intersection Installation Group
5	Intersection Installation Group (Emergency Signal Preemption)
6 & 7	Publicly-Owned CVO Installation Group / Transit Vehicle Data Transfer / Publicly-Owned (AEI / ETC / Parking / Access Control)
8	Mobile Location Interrogation Group
9	Automated Highway Systems
10 & 11	Privately-Owned (AEI / CVO / ETC / Parking / Access Control / Drive-Thru)

The assignment of channels in Table 1 was selected for its ability to minimize the need to coordinate functions or information between applications. The in-vehicle signing installation group was assigned two channels so that a portable sign or construction information could be assigned a specific channel and reduce its interference on nearby fixed in-vehicle signing beacons. Three channels were assigned to the intersection installation group: two channels were assigned to help coordinate assignment of channels of nearby intersections and one channel to help handle emergency signal preemption. The publicly-owned CVO installation group, ETC application and short-range beacons were assigned two channels for coordination of adjacent installations or multiple beacons in close proximity. Channels were set aside for the specialized applications of mobile location interrogation and automated highway systems (channels 8 and 9). Finally, two channels were set aside for privately-controlled (owned) installations such as parking access or fee collection.

Thus far in the analysis, it has been assumed that sufficient bandwidth is available to implement the channel assignments listed in Table 1. However, there is a pressing need to limit the allocation of spectrum to allow the band to be shared more easily with other users. In an

example of a similar allocation of spectrum, there are 26 MHz available in the 902 to 928 MHz band, of which only 12 MHz of continuous spectrum are assigned to DSRC applications. Therefore, the analysis will try to reduce the use of bandwidth to the minimum reasonable amount. The analysis will now address interference mitigation assuming fewer channels are available, and will address channel assignments with fewer channels available.

The number of channels required for DSRC can be reduced from those listed in Table 1 by implementing other interference-mitigating techniques. The following paragraphs will describe some of the ways to reduce the number of channels required for DSRC.

3.4.2 Eliminating Channels 2 and 4

The number of channels required for DSRC in-vehicle signing and intersection installation groups can be further reduced by eliminating the distinction between the functions. For example, in-vehicle signing will probably be handled by intersection control beacons rather than separate in-vehicle signing beacons at intersections. Only in locations away from intersections will specific in-vehicle signing beacons be used. Therefore, if the distinction between the functions of channels 1 and 2, and between 3 and 4 is removed, then the functions of the four channels can be consolidated into channels 1 and 2.

3.4.3 Eliminating Channel 5

Signal preemption is very important and requires guaranteed communications channel availability for safety and reliability. However, a separate channel is not required if specific time slots are available only for emergency communications. This would not interfere with collision avoidance because the beacon would send a code directing all tags to listen and not transmit during a collision avoidance message.

A modified slotted aloha scheme is used as an example, below, to show how it can allow virtually instant access for emergency vehicles.

Within a frame in a slotted aloha scheme there are communications time slots and activation time slots. The activation slots are usually much smaller than the communications time slots and are used by in-vehicle tags to announce their “desire” to communicate with the beacon. A tag randomly chooses an activation slot and quickly announces its identification number to the beacon. The beacon then announces to the tag, using the identification number, when it is permitted to communicate. Occasionally, two tags choose the same activation slot and they cause mutual interference such that one or both identification numbers are not received by the beacon. To allow assured communications with emergency vehicles, a single activation slot can be dedicated for emergency vehicles only and the beacon can be programmed to give first priority to the emergency vehicle tags. This, in effect, will give emergency beacons a separate “channel” in time to communicate with the beacon.

3.4.4 Consideration for the Elimination of Channel 3

The second intersection beacon channel would not be needed if the intersection beacons could use time-sharing. Intersection beacons communicating with tags in overlapping or closely spaced coverage areas could alternate communications times such that they would not both operate at the same time. However, the intersection beacon provides a collision warning signal for which every fraction of a second is critical. The intersection collision avoidance signal must not have a mandatory off time and therefore must be installed with two channels at many intersections. Therefore, channel 2 must be preserved.

3.4.5 Consideration for the Elimination of Channels 10 and 11

The private channels can be removed from the list of required channels if the distinction between public and private toll collection, parking, access control and drive-thru beacons could be removed. However, the rules for assignment and operation of these channels may be different for a public organization compared to a private organization. Additionally, even though each of the private channels is intended for very-short-range operation of 5 to 10 feet, a large deployment of private installations could make operating safety-critical systems on the same channels difficult. Finally, interference between private short-range beacons is prevented by alternating the assignment of channels between adjacent businesses or lanes of a business installation. Therefore, these two channels must remain.

3.4.6 Final Suggested Channel Assignment

The final suggested channel assignment for DSRC, after eliminating those channels as described above, is shown in Table 2.

Table 2. Final Suggested Channel Assignment for DSRC Systems

Channel #	Description
1 & 2	In-Vehicle Signing and Intersection Installation Group
3 & 4	Publicly-Owned CVO Installation Group / Transit Vehicle Data Transfer / Publicly-Owned (AEI / ETC / Parking / Access Control)
5	Mobile Location Interrogation Group
6	Automated Highway Systems
7 & 8	Privately-Owned (AEI / CVO / ETC / Parking / Access Control / Drive-Thru)

In this assignment, two channels are set aside for mobile location interrogation and automated highway systems. The mobile location interrogation channel is set aside for reasons of interference mitigation. The automated highway systems channel is set aside to handle the potentially time-critical and distinct operations of that system.

The channel assignment presented in Table 2 is one logical compromise between the desire for more channels for increased functionality and ease of implementation, and the practical limitations on available bandwidth. However, it is important to mention that, for channels used in

the same installation group, it is desirable to separate the assigned frequencies as much as possible. This will further reduce the interference potential from devices located close to each other.

3.5 Deployment of the Channel Assignments

To clarify the potential deployment of beacons using the channelization plan just presented, the following paragraphs explain example deployment scenarios for each of the installation groups or DSRC applications described in Section 3.3. The Section also discusses how the assigned channels prevent interference in these deployment situations.

3.5.1 In-Vehicle Signing Installation Group Channel Usage

The applications in the in-vehicle signing installation group (in-vehicle signing, railroad crossing warning, traffic network performance monitoring, and traffic network performance feedback) are implemented by using the assigned channels as shown in Figure 11. In the case of the multi-lane highway, channel 1 is assigned to mainline antennas that are spaced 1/2 mile to 1-1/2 miles apart. The systems use a TDMA protocol to communicate with multiple vehicles in the roadway. The antenna's coverage drops off rapidly as the pattern extends past the lanes of the roadway on either side. Therefore, the antennas are spaced far enough apart both axially and laterally to avoid interference. The beacons placed in the on and off ramps that communicate with one vehicle at a time need only a small capture zone. So, these antennas could be pointed down to minimize their signal footprint and maximize the rejection of signals from other beacons. Used this way they could also use channel 1 in most cases. However, the location of an off or on ramp close to a fixed main-line beacon would occasionally require the use of channel 2. See Appendix D for the sample calculation of reuse distance. Although, the most frequent potential source of interference would be the off-line verification, and that would use channel 5. Figure 12 shows how the channels would be used in a railroad crossing installation. Channel 1 would be used in the upstream warning beacons, placed 300 feet to 1/2 mile in both directions away from the intersection. Channel 1 would also be used for both antennas at the crossing. The beacons at the crossing would not interfere with the pre-warning beacons because they would be out of interference range. Since the antennas used in this arrangement would have a high signal rejection rating in the rear antenna pattern, placing them back-to-back does not cause interference.